

**A SEARCH FOR CHARMED PARTICLES
IN NEUTRINO INDUCED REACTIONS
AND
A STUDY OF LIGHT-ION COLLISIONS
AT VERY HIGH ENERGY**

BY

GÖRAN CLAESSION



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LOREN C. LASSON



JUNE 1987

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This thesis is based on the following papers:

- I On the production of thick pellicles of Kodak NTB-3
nuclear track emulsions
Nucl. Instr. and Meth. 180 (1981) 441
(together with G. Ingelman and K. Söderström)

- II Detection of short-lived particles in nuclear emulsions
Nucl. Instr. and Meth. 165 (1979) 1
(together with G. Ingelman, B. Andersson, K. Söderström
and I. Otterlund)

- III A search for very short-lived particles produced by
neutrinos in nuclear emulsion
Lund preprint LUIP 8203
(together with G. Ingelman and K. Söderström)

- IV A method for analyzing elastic scattering data sampled
with the SFM-detector at the CERN ISR
Lund preprint LUIP 8312
- V Measurement of $\alpha\alpha$ and αp elastic scattering at the
CERN ISR
Phys. Lett. 117B (1982) 131
(Bell et al., CERN-Heidelberg-Lund collaboration)
- VI Momentum distributions of nuclear fragments in $\alpha\alpha$
collisions at $\sqrt{s} = 125$ GeV
CERN/EP/83-109 aug 10, 83 (to be submitted to Phys. Lett.)
(Bell et al., CERN-Heidelberg-Lund collaboration)
- VII Transverse momentum distributions of hadrons produced
in $\alpha\alpha$ and αp collisions at the CERN Intersecting
Storage Rings
Phys. Lett. 112B (1982) 271
(Bell et al., CERN-Heidelberg-Lund collaboration)

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The first three papers concern the neutrino experiment E553, a search for short-lived particles, at FNAL(Fermilab), Chicago. Two of them describe development of experimental methods for the experiment. The third paper is a report on a search for very short-lived particles in a sample of neutrino events from the experiment.

The remaining papers deal with experimental methods and results from the experiment R418 at the CERN ISR, $\alpha\alpha$ and αp collisions studied with the Split-Field-Magnet detector (SFM-detector).

The subject of the papers IV and V is elastic scattering.

In paper VI the break-up of α particles is discussed and paper VII treats hadron production at large transverse momenta.

1. The neutrino experiment E553

(Cornell-Lund-Oklahoma-Pittsburgh-Sydney-Toronto collaboration)

This experiment aimed at fundamental phenomena in physics. Its goal was to measure the properties of charmed particles and other possible short-lived particles.

Charmed particles are built by two or three quarks, at least one of which is a charmed quark (correspondingly for anti-charm). At this date 5 quarks have been confidently found, though always confined within larger objects: u(up), d(down), s(strange), c(charm) and b(beauty,bottom). A sixth quark is expected, on a more or less firm ground - the t(truth,top)-quark. So far the searches for this wanted object have been in vain.

In the standard theories of today the quarks, together with the leptons and a number of particles mediating their interactions, are thought to be the building blocks of matter. Whether all, or some of these, are truly fundamental, i.e. 'atoms' in its original meaning, or not is beyond present knowledge.

Charm was predicted in 1970 [1], and in 1974 the first signal that such particles belonged to the real world came - the J/ψ particle. This particle is in a sense not a truly charmed particle as it is built by one charmed quark and one anti-charmed.

In 1977, when the experiment was initiated, the properties of charmed particles, such as D, F (mesons) and Λ_c (baryon), were almost unknown, although theoretical expectations and some experimental indications existed. Obvious features to investigate in the experiment were: life-times, production cross sections in neutrino reactions, decay channels and masses.

Within reach of the experiment were also particles containing the b-quark, although the expected production rate was low. Since it was an experiment in a new field, both theoretically and experimentally, unexpected phenomena could also occur.

As a curiosity it might be worth to mention that, quite likely, a charmed particle was first observed in an emulsion chamber detector exposed to cosmic rays [2] in the year of my birth, though naturally not interpreted as such.

1.1 General outline of the experimental design

A high-energy neutrino beam was chosen for the experiment. The main advantage of this beam is the expected high production rate of charmed particles. For sufficiently high energy of the neutrinos 5-10% of their reactions are expected to produce charm. The corresponding rates for hadron, muon and photon beams are roughly factors of 10 smaller; the production rate depends, however, on beam particle, beam energy and target. Higher beam energies are also needed here because charm is supposed to be conserved in strong and electromagnetic interactions;

therefore there will always be associated production of charm and anti-charm in the charm-producing reactions, with correspondingly higher energy thresholds for charm production.

An obvious disadvantage of neutrinos is, of course, their small reaction probability, which had to be compensated by a relatively large target.

Neutral beam particles also had the advantage of a smaller number of background tracks in the nuclear emulsion, which was chosen as target and vertex detector (the emulsion was the main concern of the Lund group).

The superior spatial resolution of nuclear emulsion (some tenths of a μm) as compared to other available track detectors (typically a few $\cdot 100 \mu\text{m}$) was the reason for this choice as the expected life-times of charmed particles were of the order of a few times 10^{-13} s [3], corresponding to flight-paths of the decaying particles around $100 \mu\text{m}$. To resolve the production and decay vertices the resolution of nuclear emulsion was needed. (In 1983 the situation is somewhat different — the small rapid-cycling bubble chambers, for instance, have a resolution of $50 \mu\text{m}$ or even better. This can still not compete with nuclear emulsion, but it can, to some extent, be compensated with larger data samples.)

The vertex of the neutrino interaction had to be predicted in the emulsion within a few mm^3 , otherwise the scanning for ν events in the emulsion would have been too time consuming. For this purpose a new type of detector was developed, a small self-marking spark

chamber, which was to be placed immediately downstream of the emulsion.

A number of such spark chambers, together with a magnet and optical spark chambers would provide momentum measurements of the produced charged particles.

A large calorimeter was constructed for energy measurements of both charged and neutral particles and for particle identification. The large-scale use of a plastic flash-tube read-out system in the calorimeter was another innovation, developed particularly for this experiment.

1.2 The experimental set-up

The wide-band neutrino (ν_μ) beam at FNAL was used in the experiment. The momentum spectrum of the neutrinos was thus very broad; starting from almost zero, with the peak-value around 10 GeV/c, it extended to above 200 GeV/c. Charm production required incident ν momenta of at least ~ 20 GeV/c. Thus the main part of the interesting ν events had incident momenta of the neutrinos from ~ 20 GeV/c up to some 70 GeV/c (there were only few neutrinos available with very high energy).

The experimental set-up was located in Lab C at Fermilab, about 2 km downstream of the primary proton target. The transverse extension of the neutrino beam was here of the order of some meters.

The target consisted of 15 litres of Kodak NTB-3 nuclear track emulsion. The about 15 000 emulsion pellicles, which we made from gel (described in paper I) at Fermilab some weeks before the scheduled run, had each a size of $600\text{ }\mu\text{m} \times 8.5\text{ cm} \times 2.0\text{ cm}$. They were assembled to stacks of size $7.5\text{ cm} \times 8.5\text{ cm} \times 2.0\text{ cm}$. These stacks were then mounted in 25 emulsion/spark chamber modules. The exposure to the beam was horizontal, i.e. the neutrinos entered the emulsion pellicles parallel to its surface. The small size in the beam direction of the pellicles, 2.0 cm, was chosen to suppress the occurrence of electromagnetic cascades of charged particles in the emulsion target and the self-marking spark chambers – the main instrument for event prediction in the emulsion. Such showers could have caused serious problems for these chambers. The potential problem was low efficiency of the spark chambers, when many ionizing particles passed close together.

The size of the electrodes of the self-marking spark chambers was $10\text{ cm} \times 50\text{ cm}$. Half of the electrodes were aluminum plates of thickness $\sim 0.5\text{ mm}$, half were glass plates coated with a thin aluminum layer, where the sparks caused small holes. Both coordinates of the transverse directions to the beam were recorded simultaneously with this read-out system – in contrast to optical spark chambers, read out by means of pictures in different views, sometimes having spark-ambiguity problems: 'which spark is which in the different projections?'.

Figure 1 demonstrates the operation of these chambers.

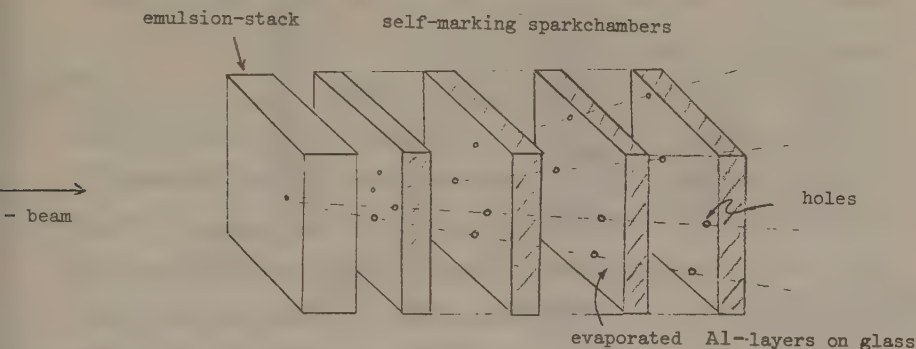


Figure 1

EMULSION-SPARKCHAMBER MODULE

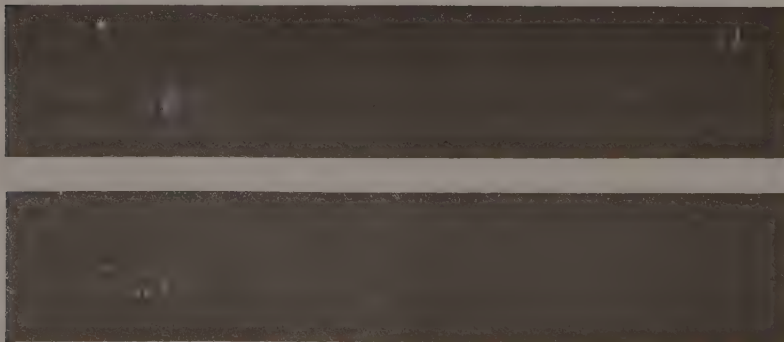
This read-out system also meant improved resolution because we did not have to go via pictures to get the coordinates. The chambers also served as optical spark chambers, however, — they were photographed in one view. The events in the emulsion were located within a few mm^3 with these spark chambers.

Figure 3 displays a top-view of the E553 apparatus, where the described parts can be seen.

The target modules were followed by the analyzing magnet. Its gap had a size of $2.4 \text{ m} \times 0.61 \text{ m}$. The length in the beam direction was 0.9 m . The field strength was 0.8 T and the bending power $\int B dl = 360 \text{ MeV/c}$.

The magnet was followed by optical spark chambers with thin aluminum foil electrodes. They were photographed in two views. Measurements of momenta were here done with $\Delta p/p \approx 0.05$.

Finally came the calorimeter. The active elements were plastic flash-tube chambers with optical read-out in one dimension. The first 5 chambers were not preceded by any absorber; they served as a tracking device for charged particles entering the calorimeter. The next 15 chambers were each preceded by 1 radiation length of lead, the next 30 by 5 cm of iron and the last 7 by 10 cm of iron. Electromagnetic cascades thus developed early, mainly in the lead, while hadronic showers, including cascades from neutral hadrons, appeared deeper in the calorimeter. Generally, the muons penetrated the whole calorimeter, through the 13.5 nuclear inelastic absorption lengths of material. The calorimeter was read out by means of a Fresnel lens/parabolic mirror system with a camera at the focus. Figure 2 shows two pictures of good events. The beam direction is from the left. The penetrating muons are clearly visible, indicating charged current interactions, as well as cascades, electromagnetic or hadronic in origin.



Figure

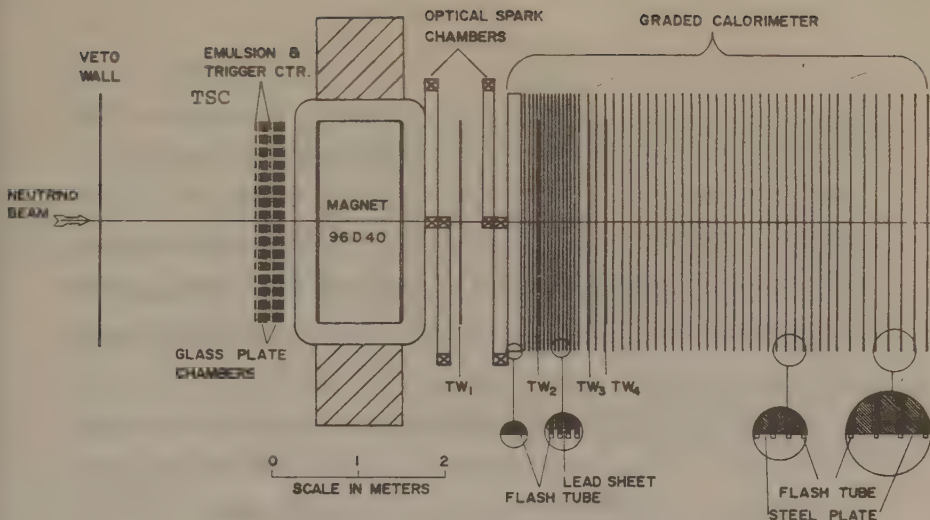


Figure 3

1.3 The trigger

TSC were counters immediately following the emulsion target. TW1 came in front of the whole calorimeter and TW2 followed the first 5 radiation lengths of lead. TW3 and TW4 then followed one and two collision lengths of iron, respectively. In front of the whole apparatus, about two meters upstream of the emulsion target, was the veto wall (VW). The trigger was $\overline{VW} \cdot TSC \cdot TW1 \cdot TW2 \cdot TW3 \cdot TW4$. For a part of the run TW4 was, however, removed from the trigger. In the scintillators TSC, TW2, TW3 and TW4 several passing minimum-ionizing particles were required in order to suppress the least energetic neutrino interactions, i.e. interactions below the charm-production threshold, from the data sample.

1.4 Run and analysis

The seven week run ended in the beginning of March 1979. A total number of $3.5 \cdot 10^{18}$ protons on the primary Be-target was used. The proton energy was either 400 GeV or 350 GeV, about equally divided in running time. We got ~ 3000 triggers in the run (150 - 200 ν events were expected in the emulsion).

A preliminary analysis was made during the run, allowing us to pull out emulsion pellicles while still running and put the remaining emulsion pellicles in the beam again. The reduction of the emulsion target was here negligible.

In this first analysis we scanned the pictures of the self-marking spark chambers in search for good neutrino event candidates, but we also used the information from the thin-foil spark chambers and the calorimeter.

The coordinates of the spark-evaporated holes in the electrodes of the self-marking spark chambers were then digitized by means of an optical projection device and a magnetic digitizing table. The vertex position in the emulsion was estimated by extrapolating the straight lines fitted to the coordinates of the holes in the 6 spark chamber electrodes. Initially, the pattern recognition of the hole coordinates, to find the event in the spark chamber, was done manually, later it was done by computer routines.

About 6 pellicles, with a total thickness of ~ 4 mm, centered on the predicted vertex, were removed from the stack, processed and scanned for events.

The sensitivity of the emulsion was such that minimum-ionizing particles produced tracks with ~ 33 grains/100 μm . Thus such tracks were easily seen, but the background, mainly tracks from low-energy electrons, was correspondingly large. Tracks associated with the neutrino beam contributed only a little to the accumulated background in the emulsion.

Several different scanning strategies were applied. Mainly we performed area (= 'volume') scanning around the search coordinate, but also back tracking of exit particles in the emulsion was used. The latter method was applied in two cases:

- 1/ Not finding the predicted event through area scanning could be due to the event being a 'white star' (or almost 'white'), i.e. an event with no visible target fragmentation, making it more difficult to see it in the emulsion. A rescan was therefore done with this method.
- 2/ When scanning for decay vertices associated with an already found ν event. In particular, the decay of neutral particles would have been difficult to detect by area scanning.

In the search for charm and other possible short-lived particles we also applied a method (see papers II and III), where we could detect life-times down to 10^{-15} s.

1.5 The results

43 neutrino events were found in the emulsion out of ~ 300 search candidates - only a subsample of these candidates were considered as 'good'. The limited statistics achieved was mostly due to the short effective running time; for several reasons the start-up of the experiment was delayed several weeks.

Four events involved possible charm production. One of these, which also contains a particle with high $p_{\perp}$, is still being debated and analyzed. Another one is discussed in paper III.

1.6 The papers related to the experiment E553

Paper I

On the production of thick pellicles of Kodak NTB-3 nuclear track emulsion.

When E553 was in preparation it was difficult to get suitable commercially available emulsion in pellicle form. We needed good sensitivity to minimum-ionizing particles in order to detect the expected decaying particles and their decay products. As a result of several tests we performed in Lund, we found that the sensitivity of the available emulsion pellicles was low and, furthermore, unpredictable. The adhesion to the glass in the

processing was also poor, sometimes causing severe distortion of the ready pellicles.

Kodak NTB-3 nuclear track emulsion had the advantage of being very sensitive - ~ 33 grains/100 μm for minimum-ionizing particles - but a drawback was that the emulsion was only available in gelform. Emulsion gel is the stage of emulsion before it becomes pellicles. The water in the gel has to be removed. The emulsion shrinks about a factor of 8 as a result of this, and pellicles of suitable size has to be made.

Nevertheless we decided to use Kodak NTB-3, and therefore we had to prepare a large scale production (15 litres of ready pellicles were produced) of emulsion pellicles at Fermilab within a period of about 4 months. The procedure to make pellicles from gel is - very simplified - to heat the gel a few centigrades above the melting point, then the gel is poured on sheets of plexiglass and allowed to dry for some days. The resulting large pellicle is then cut to pieces of suitable size. This procedure, which in practise turned out to work well, is the subject of paper I.

Paper II

Detection of short-lived particles in nuclear emulsions.

The life-time of charmed particles was expected to be of the order of a few times 10^{-13} s [3]. Some observations also poin-

ted in this direction [4], some indicated substantially shorter life-times [5]. The life-times being much longer than 10^{-13} s was quite unlikely; if so, charm should have been easily detected in, for instance, the existing bubble chambers. Events with charm production should then have had similar characteristics to events with strangeness production. Much shorter life-times than anticipated were, however, still possible and also supported by some data as mentioned above. An objective method to detect decays that can not be seen visually in the microscope was therefore developed.

The method is to digitize the positions of the grains of the tracks in the investigated event, with as high accuracy as the grain-size of the emulsion permits, then fit straight lines to the tracks and, finally, to apply χ^2 -tests of various vertex hypotheses. If two or more vertices are found, it can be a signal of a decay of a short-lived particle. Life-times down to 10^{-15} s can be detected with this method, corresponding to flight-paths of about 1 μm of the decaying particles.

Now, in 1983, it can be added that, although charm can be detected with other methods, common expectations on the life-time of the b-quark is in the region $10^{-14} - 10^{-13}$ s, where this method is applicable. It should also be possible to apply the method in the search for charm in the now existing small bubble chambers.

Paper III

A search for very short-lived particles produced by neutrinos in nuclear emulsion.

The method of paper II was applied in order to search for decay vertices of short-lived particles in the neutrino events sampled in E553. This was a complement to the visual area scanning, done earlier. Much shorter life-times could be detected here, but an additional reason was, that the region immediately downstream of the main vertex was sometimes difficult to investigate because of the many grains in that region. There were also some new experimental data [6] (in the end of 1979), indicating that the life-time of the D^0 -meson was significantly shorter than anticipated, giving us an additional reason to investigate the ν events closer.

In one of the investigated events we detected a kink on one track, i.e. the track suddenly changed direction, which could have been due to a decay of a charmed particle (or something more trivial) into one charged particle and one or more neutrals. Unfortunately no downstream information, momentum measurement by the optical spark chambers and/or energy deposition in the calorimeter, was available for this particular event. Thus we could not go further than what is stated in the paper: possible charm production.

2. The light-ion experiment R418

(CERN-Heidelberg-Lund collaboration)

The second main part of this thesis concerns $\alpha\alpha$ and αp collisions at the CERN ISR. The storage of α particles in the ISR opened up a new energy domain for collisions between nuclei. In the case of $\alpha\alpha$ collisions the total available energy in the centre-of-mass system (CMS) was $\sqrt{s} = 125$ GeV – the highest $\sqrt{s}$ in any accelerator produced collisions before the $p\bar{p}$ collider at CERN came into operation. For αp collisions we had $\sqrt{s} = 88$ GeV. Calculating the corresponding values for nucleon-nucleon collisions gives $\sqrt{s}_{NN} = 31$ and 44 GeV for $\alpha\alpha$ and αp collisions, respectively.

To motivate studies of light- or heavy-ion collisions at high energies it is crucial that such collisions not only can be treated as superpositions of individual nucleon-nucleon collisions. This is the subject of several current experimental activities. The investigation of an anomalous nuclear enhancement in large- $p_{\perp}$ hadron production (see paper VII) is one example.

One of the more spectacular expectations in the field of ion-physics at high energy is the quark-gluon plasma [7]. When high enough energy/particle densities are reached, e.g. as a result of nuclei colliding at very high energy, a phase transition may occur – from hadronic matter into a state where the individual hadrons lose their

identity and only quarks and gluons are relevant objects. The discovery of such a state of matter could have cosmological consequences – it is possible that all matter was in a quark-gluon plasma state in some early stage of the development of the Big Bang, the origin of our observable universe in the standard theories of today.

Although the α particle is mostly considered too small to create an equilibrium plasma state it is still possible that a quark-gluon plasma can be created in the very high-energetic $\alpha\alpha$ collisions at the ISR. Some anticipated signals of a quark-gluon plasma are enhanced production of strange particles, dilepton emission and direct photons. The study of $\alpha\alpha$ and αp collisions will, in any case, provide a link between particle physics and the fastgrowing field of heavy-ion physics at high energies.

2.1 The run

The run, in July 1980, was divided in two parts: first there were α particles in both rings for 60 hours, followed by 60 hours with α particles in one ring and protons in the other. The obtained luminosities in a standard intersection were $3 \cdot 10^{28} \text{ cm}^{-2}\text{s}^{-1}$ and $8 \cdot 10^{29} \text{ cm}^{-2}\text{s}^{-1}$ for $\alpha\alpha$ and αp beams, respectively.

In addition to R418 several other experimental groups took data – complementary information was gained in this way. R418 could, for instance, not measure large- $p_{\perp}$ production of neutral

hadrons, which was done by R110 and R806. Different kinematical regions were available for the set-ups in the different intersections of ISR, e.g. large- $p_{\perp}$ charged hadron production as measured by R807 and R418 and measurement of elastic scattering by R210/211 and R418.

By means of different triggers, some were set up specifically for the α run, in the SFM-detector, a number of quite different physics subjects could be studied in experiment R418: soft processes like elastic scattering and break-up of α particles, and hard processes like particle production in inelastic collisions and large- $p_{\perp}$ hadron production.

2.2 The Split-Field-Magnet detector

The SFM-detector is well described elsewhere [8], so I will only give a simplified description of it, adding a top-view figure of the apparatus (figure 4). There are also some figures in the papers IV to VII.

There are three magnets in the detector. The most important is the Split-Field analyzing magnet, so called because the field points up on one side of the intersection region and down on the other side. This arrangement is needed to correct the beam paths in a proper way. The maximum field strength is 1 T, the air-gap is 1m high and the field volume is 30 m³.

There are also two compensator magnets with the main purpose to adjust the trajectories of the non-interacting beam particles, although for small-angle tracks they also fill an analyzing purpose.

Multi-Wire-Proportional Chambers (MWPCs) are used as tracking device for charged particles — the total number of wires is about 70 000.

In the large- $p_{\perp}$ trigger regions there are two gas Cerenkov counters, Č1 and Č2, to distinguish between pions and heavier particles.

There is also a time-of-flight counter system (TOF), used in the large- $p_{\perp}$ and elastic triggers. The scintillators are also used for charge separation of passing particles.

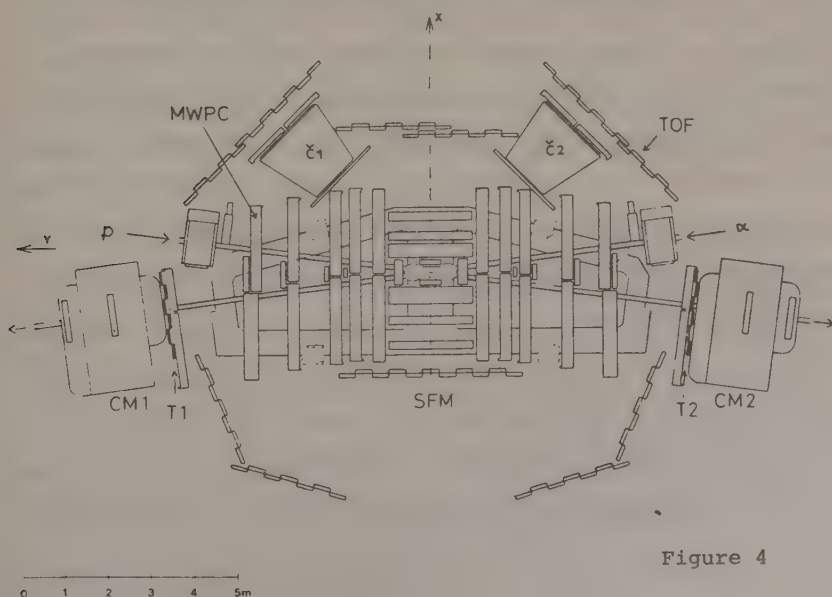


Figure 4

In common for the investigations reported in the papers IV, V and VI is that we mainly used the 'forward region', i.e. small angles to the beam, of the SFM-detector. The detector systems thus available were the MWPCs and scintillators covering about the same region.

2.3 The papers related to experiment R418

Paper IV

A method for analyzing elastic scattering data sampled with the SFM-detector at the CERN ISR.

For the α run a special soft-ware trigger for elastic collisions was developed within the R418 collaboration. A method to analyze events obtained with this trigger was also developed. Improved resolution and less time consumption in the computer per event, compared to already existing computer routines, was achieved with this method. Paper IV, which is almost purely technical – the physics is to be found in paper V –, is a report on the development of, and a summary of the method used in the analysis of the elastic trigger data of R418. The method has later also been applied to $p\bar{p}$ elastic scattering in the SFM-detector. .

Paper V

Measurement of $\alpha\alpha$ and αp elastic scattering at the CERN ISR.

Elastic scattering is described by a well established theory - the multiple scattering theory of Glauber. The basic input to the theory is the nuclear structure and the elastic scattering amplitude. Thus these features can be tested when experimental data is compared to Glauber-model calculations. Deviations from this model have been observed in some high-energy data. Therefore the model has been extended to allow the creation of intermediate inelastic states: after the first scattering the projectile may come in an excited state, scatter again and return to the ground state.

The energies in this investigation were very high compared to earlier measurements, allowing a test of the need for intermediate inelastic states in a new energy regime. The investigated t -region was $t \in [-0.8, -0.25] \text{ GeV}^2/c^2$, where t is the squared 4-momentum transfer in the elastic collision. The t -region closer to $0 \text{ GeV}^2/c^2$ was measured by exp. R210/211.

The data was compared with earlier measurements, at lower energies, and with Glauber-model calculations, with and without corrections for intermediate inelastic states. The inelastic correction was needed to get agreement with our data as to the case of $\alpha\alpha$ elastic scattering. For αp elastic scattering data the correction was small and the measurement uncertainties did not allow any definite conclusions.

Paper VI

Momentum distributions of nuclear fragments in $\alpha\alpha$ collisions
at $\sqrt{s} = 125$ GeV.

This paper concerns the break-up of α particles at very high energy. A large sample of events, about 100 000, sampled with a special trigger, was studied. The trigger demanded one or two large-momentum particles at small angle to the beam on each side of the intersection region and vetoed events with particle production at large angles. We analyzed the $p_{\perp}$ (transverse momentum) and p_L (longitudinal momentum in the rest frame of the fragmenting α particle) distributions of protons and deuterons.

The widths of the p_L -distributions were in reasonable agreement with a model for fragmentation of nuclei [9] where the Fermi motion within the fragmenting particle rules the momentum distributions of the nuclear fragments. We observed, however, slight asymmetries in the p_L -distributions and, furthermore, that their peak-values were shifted from zero. These observations were not consistent with [9]. The $p_{\perp}$ -distributions differed more dramatically from [9], with observed widths more than a factor of two too large. The assumption that quasi-elastic scattering among nuclear constituents, together with Fermi-motion, ruled the momenta of the fragments in the kinematical region we observed with our trigger was, however, in consistency with our data. The deuteron spectra indicated that the deuterons we observed might have been formed in final-state interactions.

Paper VII

Transverse momentum distributions of hadrons produced in $\alpha\alpha$ and αp collisions at the CERN Intersecting Storage Rings.

The subject of this paper was one of the main reasons for the storage of α particles in the ISR. The common opinion has been that single hard scattering between point-like objects rules hadron production at large transverse momenta. Thus the expected yields of hadrons at large $p_{\perp}$ were 16 and 4 times the yield in pp collisions for $\alpha\alpha$ and αp collisions, respectively. An enhancement over these factors had earlier been observed in an experiment at Fermilab studying proton-nucleus collisions with proton energies of 200 - 400 GeV [10]. This effect was named the 'anomalous nuclear enhancement' (ANE).

The result of the investigation reported in paper VII, charged hadron production at large transverse momenta in high-energy $\alpha\alpha$ and αp collisions, was consistent with the ANE, although the error bars were too large to verify the existence of the effect. Data from other ISR-experiments gave also some support for the existence of the ANE-effect [11].

The ANE-effect will be further tested in a new run at ISR in August 1983 - hopefully the experimental situation will be more clear when this new, in part complementary, data has been analyzed. The theoretical interpretation of the ANE is still under debate - multiple scattering effects, formation of big bags and effects of Fermi motion have been mentioned [12].

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I am also very grateful to Professor Hans Ryde for his support and interest.

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Finally, to my friends and colleagues at the department of Cosmic and Subatomic Physics in Lund and others having some share in this work and in making these years so interesting and enjoyable that I would not like to have them undone - that is a high praise - : thank you.

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- [8] See ref. 7/ in paper VII
- [9] See ref. 10/ in paper VI
- [10] See ref. 1/ and 2/ in paper VII
- [11] See ref. 9/ and 10/ in paper VII and:
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